Semiannual Report of the

HAYSTACK OBSERVATORY

NORTHEAST RADIO OBSERVATORY CORPORATION

NAS 9-7830

15 JULY 1972

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42

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ACKNOWLEDGMENTS

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Incremental support of radar studies of distant satellites is provided by MIT Lincoln Laboratory under Air Force Contract F 19628-70-C-0230.

FOREWORD

These reports are intended to summarize typical work at Haystack for the benefit of (a) the NEROC officers and Board of Trustees (b) sponsors, particularly those to whom formal reporting is a contractual obligation, and (c) others having a basic interest in Haystack and/or the sorts of work done here. The reports also provide a vehicle for presentation of engineering developments and other activities of interest which might otherwise not be published.

Suggestions from readers for improvement of these reports are welcome.

Paul B. Sebring

ABSTRACT

During the first half of 1972, the Haystack antenna was utilized 82% of the time. Of this useful time, 67% was devoted to radio astronomy, 13% was spent on radar-related research, and 20% was scheduled for maintenance and/or system improvements.

Among the 32 presently active radio astronomy programs, 15 are spectral-line research, 8 involve continuum measurements, two are Haystack-Westford short-baseline interferometer projects, five are VLBI experiments and two used the spectrometric receiver with a small horn antenna.

New radiometric proposals accepted totaled 26, while 22 projects were completed. Six programs involve the Planetary Radar, and two of these use the Haystack-Westford interferometer to receive the echoes.

NORTHEAST RADIO OBSERVATORY CORPORATION

A nonprofit corporation of educational and research institutions formed in June 1967 to continue the planning initiated by the Cambridge Radio Observatory Committee for an advanced radio and radar research facility. In March 1969, by agreement with MIT and Lincoln Laboratory, its interest was extended to the existing Haystack Research Facility to seek means of increasing its availability for research. Since July 1970, NEROC has directed the research at Haystack and has had the primary role in arranging for support.

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Brandeis University
Brown University
Dartmouth College
Harvard University
Massachusetts Institute of Technology
Polytechnic Institute of Brooklyn
Smithsonian Astrophysical Observatory
State University of New York at Buffalo
State University of New York at Stony Brook
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May 1972

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NORTHEAST RADIO OBSERVATORY CORPORATION

Semiannual Report

of the

HAYSTACK OBSERVATORY

1 Jan. - 30 Jun. 1972

I. INTRODUCTION AND SUMMARY

Utilization of the antenna and associated equipment may be summarized as follows:

Use	Hours
Radio Astronomy	2391
Lunar Radar Observations	164
Planetary Radar Studies	223
Radar Observations of Synchronous Satellites	98
Total Scientific Use	2876
Maintenance & Instrumentation Improvements	706
TOTAL	3582
Idle or Lost	~786
Total Hours in ½-Year	4368

The Observatory accepted 26 new proposals for radiometric observing programs, as compared with 16 proposals accepted during the previous six-months period. An additional six radiometric programs were continued from the second half of 1971. Among the 32 presently active radio astronomy programs, 15 (47%) involved spectral-line measurements, 8 (25%) continuum measurements, 5 (16%) VLBI measurements, 2 Westford-Haystack (WESTACK) short baseline interferometer measurements, and 2 used the correlator and U490 computer for spectral-line observations with a small horn antenna. A total of 22 radiometric projects were completed during this period.

The on-going astronomical radar projects include two that make use of the Haystack-Westford (HAYFORD) interferometric radar system and four that use Haystack alone.

Table I lists new programs begun during the first half of 1972. Radar programs are also listed in this table. Even though most such projects are of long standing at the Observatory, specific proposals covering such work, similar to those required to initiate radiometric programs, were prepared for the first time during this period. The radar projects therefore appear as "new" programs.

Early in the period a new project involving the application of Haystack-developed planetary radar equipment and techniques to the characterization of satellites in synchronous or near-synchronous orbit was initiated at the request of MIT Lincoln Laboratory. Supplementary funding was provided in support of these operations and of certain improvements to the Haystack systems. Continuation of this project at a modest operating level (approximately 3-400 hr/year) is anticipated in the coming year. The work is proposed and scheduled in the same manner as the more usual astronomy programs.

A drop in hours devoted to lunar and planetary astronomy is anticipated during the coming year due (a) to decreased support arising from budget difficulties at NASA and (b) to the fact that the coming year holds fewer opportunities for planetary studies of great interest. Total radar utilization is thus expected to be only about 800 hours in the coming year.

Table II gives the status, as of 1 July 1972, of those programs continued from the previous half-year.

TABLE I

NEW PROGRAMS THIS PERIOD

1 January - 30 June 1972

PROGRAM	INVESTIGATORS	INSTITUTIONS	HRS. REQUESTED	HOURS USED THIS 1/2 YEAR	DESIGNATION
18-GHz Search for HC_3N, J = 2 to 1 Transition	D.F. Dickinson	Smithsonian Astrophys. Obs.	26	21 hrs/Complete	DICKINSON-7
25.2 to 29.9-GHz Search for New Molecular Transitions	B.E. Turner, M.A. Gordon G.T. Wrixon	National Radio Astron. Obs. Bell Telephone Labs.	168	151 hrs/Complete	TURNER-2
24.9 to 25.1-GHz Observations of Methyl Alcohol Transitions (Cont'd)	A.H. Barrett, K. Bechis, R. Martin, K.Y. Lo	Mass. Inst. of Tech.	120	168 hrs	BARRETT-10X
7.8-GHz Geodetic VLBI with Goldstone 210 ft. and Alaska	I.I. Shapiro A.E. Rogers, S.Lippincott T.A. Clark D.J. Spitzmesser	Mass. Inst. of Tech. Haystack Obs. Goddard Space Flight Ctr. Jet Prop. Lab.	200	138 hrs.	VLBI-14
8-GHz Search for Continuum Emission from Galaxy Chains	M. Kaftan-Kassim, J.W. Sulentic	State Univ. of N.Y. at Albany	48	23 hrs/Complete	KASSIM-1
22-GHz Measurements of H_2O Source Positions and Structure with Westford-Haystack Interferometer	B.F. Burke, K.Y. Lo, A.H. Barrett	Mass. Inst. of Tech.	240	158 hrs/Complete	WESTACK-2
7.8 to 8.4-GHz Search for New Molecular Transitions	P.R. Schwartz, S.A. Mango B.E. Turner, J.H. Fertel	Naval Research Lab. National Radio Astron. Obs.	64	78 hrs/Complete	SCHWARTZ-1
1.4-GHz Spectral-Line Search	P.M. Kalaghan	Harvard College Obs.	18	25 hrs/Complete	KALAGHAN-1
22-GHz VLBI Observations of H_2O Sources with NRAO 140 ft and NRL 85-ft antennas	G. Papadopoulos, B.F. Burke J.M. Moran K. Johnson, S. Knowles	Mass. Inst. of Tech. Smithsonian Astrophys. Obs. Naval Research Lab.	72 hrs/quarter	66 hrs	VLBI-15
7.8-GHz Radar Mapping of Venus with Westford-Haystack Interferometer	G.H. Pettengill R.P. Ingalls, A.E.E. Rogers	Mass. Inst. of Tech. Haystack Obs.	91	64 hrs/Complete	HAYFORD-VENUS (Radar)
22-GHz Continuum Search for Small-Scale Anisotropies in the 3°K Background	P. Crane, B.F. Burke	Mass. Inst. of Tech.	24	30 hrs/Complete	CRANE-1

TABLE I - Page 2

PROGRAM	INVESTIGATORS	INSTITUTIONS	HRS. REQUESTED	HOURS USED THIS 1/2 YEAR	DESIGNATION
19.265-GHz Search for HC_3N Transition near Galactic Center	D.F. Dickinson C.A. Gottlieb	Smithsonian Astrophys. Obs. Harvard College Obs.	14	28 hrs/Complete	DICKINSON-8
60-GHz Line Profile Measurement of Atmospheric O_2 Emission (used spectrometer only)	J.W. Waters	Mass. Inst. of Tech.	21	35 hrs/Complete	WATERS-2
7.79-GHz Measurements of H 94α in Planetary Nebulae	L.E. Goad, E.J. Chaisson	Harvard College Obs.	65	45 hrs	GOAD-2
1.6-GHz VLBI Measurements of Relative Positions of OH Sources with Algonquin Park	J.M. Moran J.G. Yen, P. Kronberg	Smithsonian Astrophys. Obs. Univ. of Toronto	72	0	VLBI-16
8-GHz Continuum Measurements of Circular Polarization from the Sun	R.M. Straka	Boston Univ./AFCRL	16	10 hrs/Complete	STRAKA-1
8 and 15.5-GHz Continuum Search for Rapid Time Variation in Extragalactic Sources	E.E. Epstein	Aerospace Corp.	224	0	EPSTEIN-1
16.56-GHz Measurements of H 73α and He 73α in Orion A	G. Papadopoulos E.J. Chaisson	Mass. Inst. of Tech. Harvard College Obs.	70	0	PAPADOPOULOS-3
22.235-GHz Measurements of Fluctuation Statistics in H_2O Emission from W49 (Cont'd)	J.M. Moran	Smithsonian Astrophys. Obs.	20	0	MORAN-1X
22-GHz Continuum Measurements of Circular Polarization from the Sun During Eclipse of 10 July 1972	R.M. Straka	Boston Univ.	16	0	STRAKA-2
8.315-GHz Search for 92α Recombination Transitions in Heavy Elements in W3 and Orion B	E.J. Chaisson	Harvard College Obs.	64	0	CHAISSON-9
8.315-GHz Measurement of 92α Transitions in W51	E.J. Chaisson	Harvard College Obs.	30	0	CHAISSON-10

TABLE I - Page 3

PROGRAM	INVESTIGATORS	INSTITUTION	HRS. REQUESTED	HOURS USED THIS 1/2 YEAR	DESIGNATION
7.876-GHz and 8.372-GHz Search for Recombination Lines from C^{++} 149α and 146α	E. J. Chaisson	Harvard College Obs.	48	0	CHAISSON-11
8.315-GHz Search for (He 92α) Recombination Line in HI Region Toward Orion B	E. J. Chaisson	Harvard College Obs.	30	0	CHAISSON-12
15.5-GHz Continuum Search for Emission from Globular Clusters	J.W. Erkes, A.G.D. Philip	State Univ. of N.Y. at Albany	64	0	PHILIP-1
22.235-GHz Measurements of H_2O Source Positions and Structure with Westford-Haystack Interferometer (Cont'd)	B.F. Burke, K.Y. Lo	Mass. Inst. of Tech.	96 hrs/2-mo. interval	0	WESTACK-2X
60-GHz Line Profile Measurement of Atmospheric Emission (Cont'd)	J.W. Waters	Mass. Inst. of Tech.	30	0	WATERS-2X
7.8-GHz Radar Measurements of Lunar Topography with Westford-Haystack Interferometer	S.H. Zisk	Haystack Obs.		164 hrs.	HAYMOON (Radar)
7.8-GHz Radar Measurements of Mercury Topography	R.P. Ingalls G.H. Pettengill	Haystack Obs. Mass. Inst. of Tech.		*	MERCURY TOPOGRAPHY (Radar)
7.8-GHz Radar Measurements of Venus Topography	R.P. Ingalls G.H. Pettengill	Haystack Obs. Mass. Inst. of Tech.		*	VENUS TOPOGRAPHY (Radar)
7.8-GHz Radar Measurements of Venus Echo Spectra	R.P. Ingalls G.H. Pettengill	Haystack Obs. Mass. Inst. of Tech.		*	VENUS SPECTRA (Radar)
7.8-GHz Radar Measurements of Mercury and Venus - 4th Test of General Relativity	R.P. Ingalls G.H. Pettengill, I.I. Shapiro	Haystack Obs. Mass. Inst. of Tech.		*	FOURTH TEST (Radar)
7.8-GHz Radar Measurements of Artificial Satellites at Synchronous Altitudes and beyond	A.F. Pensa; Gp. 96 S.H. Zisk, R.P. Ingalls	MIT Lincoln Lab. Haystack Obs.	100	98 hrs./Complete Extension Anticipated.	LL-1

* Total Hours this 1/2 year for Planetary Observations - 159.
Separate Accounting of hours will be kept in the future.

TABLE II

PROGRAMS CONTINUED FROM PREVIOUS PERIOD

PROGRAM	INVESTIGATORS	INSTITUTIONS	THIS 1/2 YR. OBS. HRS.	STATUS	DESIGNATION
8 & 15-GHz Monitoring of Quasars & Seyfert Galaxies	W.A. Dent	Univ. of Mass./Amherst	347	Continuing	DENT-1
7.79-GHz Recombination Lines, Search of Planetary Nebulae	L.E. Goad	Harvard College Obs.	51	Complete/85	GOAD-1
28 to 38-GHz Continuum Mapping Observations	G.T. Wrixon	Bell Telephone Labs.	48	Continuing	WRIXON-2
7.793-GHz Mapping of H94α Transition in W43	K.Y. Lo E.J. Chaisson	Mass. Inst. of Tech. Harvard College Obs.	57	Complete/65	LO-1
7.79-GHz Recombination Lines in Sgr B2	E.J. Chaisson, C.Gottlieb, J.A. Ball, A.E. Lilley	Harvard College Obs.		Complete/70	CHAISSON-5
7.81-GHz Observations of C118β Recombination Lines	E.J. Chaisson, A.K. Dupree	Harvard College Obs.	0	Continuing	DUPREE-2
22.235-GHz Measurement of H O Emission from W49 Signal Statistics	J.M. Moran	Smithsonian Astrophys. Obs.	70	Complete/52	MORAN-1
7.85-GHz VLBI Observations with Goldstone 210-foot Antenna	T.A. Clark, G.E. Marandino R.M. Goldstein, D.J. Spitzmesser H.F. Hinteregger, C.A. Knight, A.R. Whitney, I.I. Shapiro A.E.E. Rogers	Univ. of Maryland Jet Propulsion Lab. Mass. Inst. of Tech. Haystack Obs.	67	Continuing	VLBI-9
7.85-GHz VLBI with Goldstone 210 foot Antenna	K.I. Kellermann, B.G. Clark J.J. Broderick, D.L. Jauncey M.H. Cohen, D. Schaffer	NRAO Cornell Cal. Inst. of Tech.	92	Continuing	VLBI-10
23.1 to 25.3-GHz Search for New Sources of CH_3OH & Cont'd search for C_2H_4O	A.H. Barrett, K.Y. Lo, R. Martin, K. Bechis	Mass. Inst. of Tech.	108	Complete/108	BARRETT-10

TABLE II - Page 2

PROGRAM	INVESTIGATORS	INSTITUTIONS	THIS 1/2 YR. OBS. HRS.	STATUS	DESIGNATION
8.105-GHz VLBI: Haystack—Westford — NRAO Interferometer (4-antenna experiment)	T.A. Clark C.A. Knight, I.I. Shapiro, A.R. Whitney A.E.E. Rogers	NASA/Goddard Mass. Inst. of Tech. Haystack Obs.	141	Complete/141	VLBI-13
7.79-GHz Mapping Observations of H94α in NGC 2244	E.J. Chaisson, R. Baldwin	Harvard College Obs.	16	Complete/16	CHAISSON-6
7.79-GHz Mapping Observations of H94α in NGC 7538	E.J. Chaisson, C.J. Lada	Harvard College Obs.	59	Complete/59	CHAISSON-7
22.235-GHz H_2O Monitoring of Sources & Search for New Sources	J.A. Ball, D.F. Dickinson A.H. Barrett, K. Bechis	Smithsonian Astrophys. Obs. Mass. Inst. of Tech.	374	Continuing	BARRETT-11
16.6-GHz Observations of 73α Recombination Lines in HII Regions	G. Papadopoulos, K.Y. Lo E.J. Chaisson	Mass. Inst. of Tech. Harvard College Obs.	4	Complete/141	PAPADOPOULOS-2
8.105-GHz Haystack-Westford Baseline Calibration	C.A. Knight, A.R. Whitney	Mass. Inst. of Tech.	27	Complete/27	*WESTACK CAL.

* Haystack - Westford <u>radio</u> interferometer is designated WESTACK;
Haystack - Westford <u>radar</u> interferometer is called HAYFORD.

II. Radio Astronomy - Selected Activities

A. Continuum Programs

The Pointing Accuracy of the Haystack Antenna

M.L. Meeks and B.G. Leslie, Haystack Observatory

The water-vapor sources at 22.234 GHz, because of their extraordinary intensity and small angular size, provide excellent reference points for calibration and monitoring of the pointing accuracy of radio telescopes at short centimeter wavelengths.

During the last six-months we routinely measured the pointing errors of the Haystack antenna during two or three periods each month by observing the bright sources in W3, W49, W51 and Orion A. These measurements were made with both the Planetary Radar (PR) and Radiometer (R) equipment-boxes on the antenna. After each box change, calibration measurements were repeated to determine whether any biases have been introduced in the pointing.

Figure 1 shows the pointing errors measured between 1 January and 4 July 1972 on the source in W49, the most intense source during this period. Altogether, 115 measurements are included in this figure from observations on 13 different days. The errors were measured with an automatic antenna-control program, and successive measurements on the source are reproducible to one millidegree (3.6 arc seconds). The spread of errors in azimuth clearly remained consistent with the 2-mdeg. rms azimuth-error obtained in April 1970, when the pointing-calibration measurements were made.

The elevation errors show a wider spread than the azimuth errors because of the variability of tropospheric refraction. The refraction corrections shown here were based on measurements of surface values of the air temperature and humidity at the antenna site. This method of estimating refraction evidently fails to account for refraction on some occasions. The larger elevation errors occurred at low elevation angles, as we expected.

B. Spectral-Line Programs

Atmospheric Emission Line-Profile Measurements at 53 GHz.

J.W. Waters, R.M. Paroskie, D.H. Staelin - Mass. Inst. of Tech.

Atmospheric absorption and thermal emission at wavelengths around 5 mm (60 GHz) are dominated by resonances of molecular oxygen, O_2. Spectral-line measurements of atmospheric thermal radiation in this wavelength range provide a means of remote sensing of atmospheric temperature. Our present knowledge of atmospheric absorption (and emission) by O_2 is limited by the lack of an adequate description of the absorption for all values of atmospheric

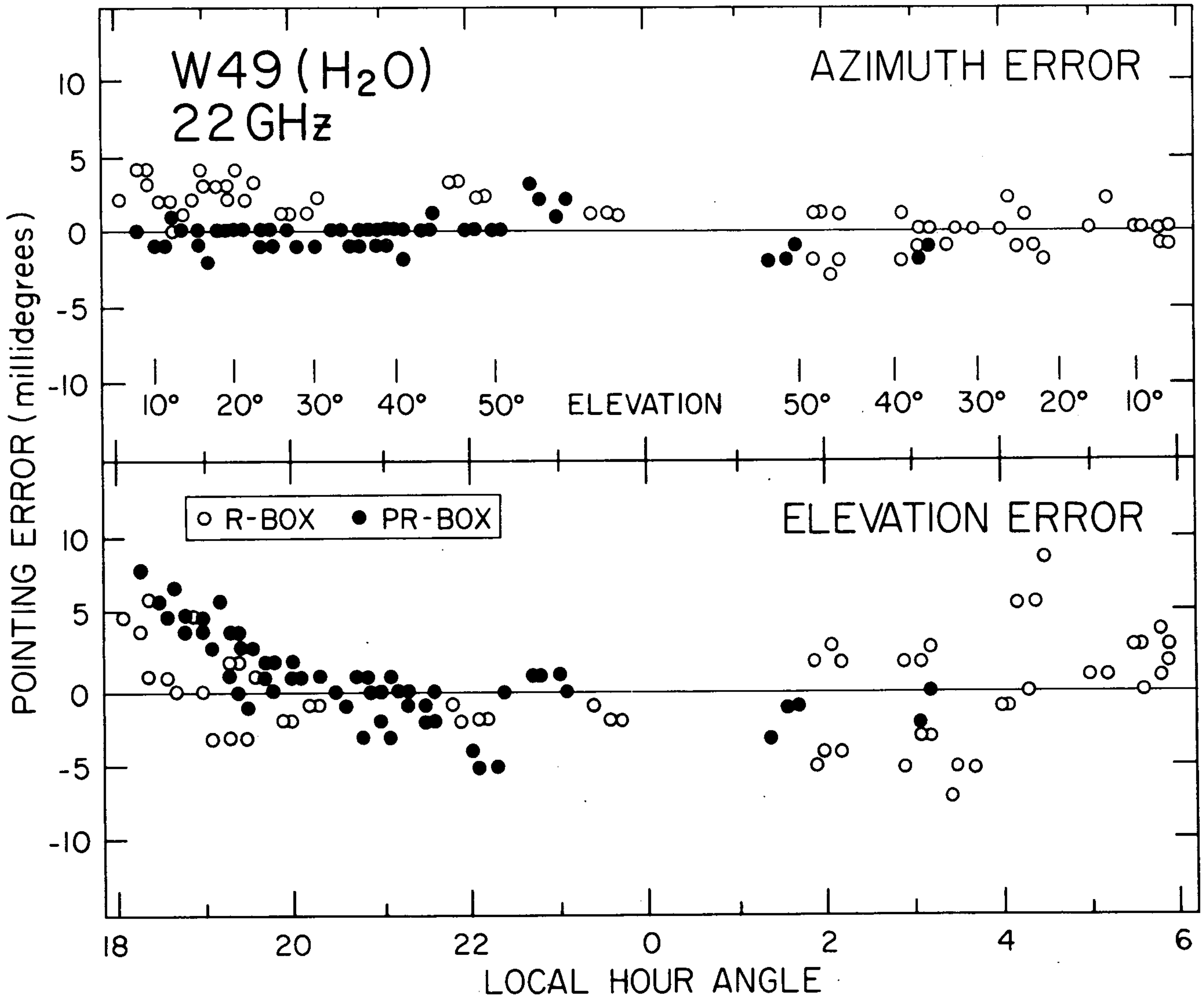

FIG. 1. HAYSTACK POINTING ERRORS
JAN.- JUN. 1972

pressure and temperature.

As part of a program to develop microwave experiments for remotely sensing atmospheric temperatures up to approximately 80 km, we used the Haystack spectrometer with a small horn antenna to measure the profile of the 27_- transition on the lower frequency edge of the O_2 band where radiation from the relatively narrow upper atmospheric emission can penetrate the lower atmosphere. The purpose of this experiment was to determine whether the line profile of an individual spin-rotation transition in the atmosphere agreed with the theoretical shape calculated by linearly superimposing the many Zeeman components of this transition. The radiometer used was developed at MIT Research Laboratory of Electronics and has a double sideband noise temperature of approximately 2000°K. The Haystack autocorrelator provided the necessary frequency resolution for spectral analysis, and a wider bandwidth filter bank was operated in parallel with the correlator. The antenna was a simple 10° beamwidth standard gain horn, located on the Haystack grounds outside the radome.

Figure 2 shows the measured and calculated emission near the center of the 27_- O_2 spin-rotation line. This particular transition contains 159 Zeeman components, all of which are contained within ± 1.5 MHz of the line center frequency of 53, 065.9 MHz, and the agreement in shape between measurement and calculation indicates one is justified in summing the Zeeman components in the region where they overlap. At frequencies away from line center the agreement between calculation and measurement is poor, as Figure 3 shows. We believe the disagreement is due to the inadequacy of the theory, which sums individual spin-rotation lines with line-width parameters empirically adjusted by other workers to fit other measurements.

Observations of H94α Radio Recombination Lines In Planetary Nebulae

L.E. Goad and E.J. Chaisson - Harvard College Observatory

With the PR-Box maser radiometer we have observed the H94α radio recombination line at 7.793 GHz in four planetary nebulae: NGC 6543, NGC 6572, IC 418 and NGC 7027. The system temperature was typically 45°K. For the observations reported here, a total predetection bandwidth of 6.67 MHz was used, which gave a spectral resolution of 5.8 km/sec. The observations were made in the total power mode, with the telescope beam switched ± 1° in right ascension every ten minutes. Equal amounts of time were spent ON and OFF source. A least squares fitting program was used to analyze the data by simultaneously fitting a gaussian profile and a linear baseline to the observed antenna temperatures. We found that by selecting only those individual integrations with linear baselines (about 50% of the total observations) the best results were obtained.

For the nebulae NGC 6543, NGC 6572 and IC 418 the observed line-to-continuum intensities yield LTE electron temperatures of 7250°K, 6350°K and 11300°K respectively. The 3-sigma errors in these estimates are ± 2000°K. Although the

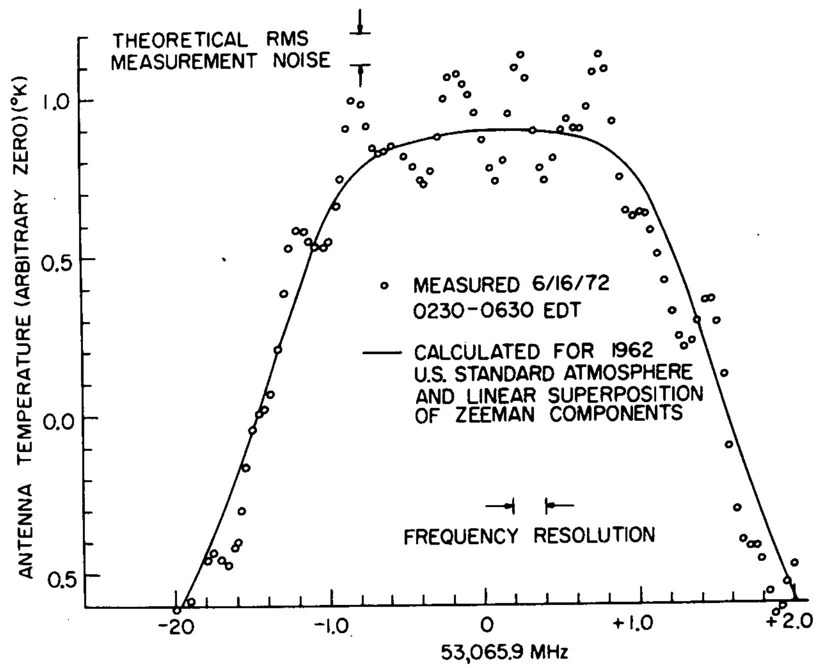

Figure 2. Atmospheric Emission Near Center of 27_O_2 Line

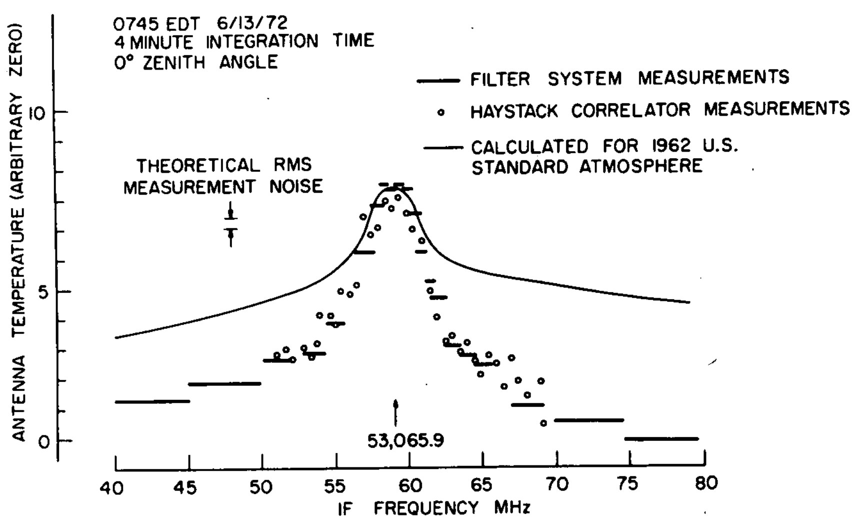

Figure 3. Atmospheric Zenith Emission from 27_O_2 Line: Calculation Vs. Measurements on Wings of Line

lines are certainly formed in non-LTE, there is insufficient data available at this time for a detailed analysis.

Observations have also been made of the peculiar planetary nebula NGC 7027. The detected line is unusually broad (44 km/sec wide at half-maximum), and comparable with the observed Hα line-width. There is, as yet, no direct evidence for Stark broadening in this very dense nebula. Further observations of this peculiar source are planned.

C. Interferometer Programs

Goldstack VLBI Observations of Quasar Structure

H.F. Hinteregger, C.A. Knight, I.I. Shapiro and A.R. Whitney - Massachusetts Institute of Technology

T.A. Clark - NASA Goddard Space Flight Center

A.E.E. Rogers, S. Lippincott - Haystack Observatory

G.E. Marandino - University of Maryland

R.M. Goldstein, D.J. Spitzmesser - Jet Propulsion Lab., CalTech.

Observations of the structure of quasars with a fringe spacing of 2 milliseconds of arc began in the fall of 1970 with the "Goldstack" interferometer consisting of the Haystack 120-ft and the Goldstone 210-ft antennas, observing at a frequency of 7.85 GHz. Since that time, two independent groups of investigators have made repeated observations to monitor the remarkable changes in quasar structure as a function of time. We report here briefly the results obtained by the group listed above. These observations are continuing on a monthly basis with each group alternately observing for a 24-hour period.

Since the initial observations in October 1970, the structure of 3C279, based on the double-source model, continues to show expansion at nearly the angular rate previously reported, a rate corresponding to ten times the velocity of light or greater if the distance to this quasar is calculated from Hubble's law. The apparent relative intensity of the component sources, however, has changed considerably. The structure of 3C273B, similarly deduced from a double-source model, also shows a roughly constant separation rate with relative intensity changes of almost a factor of ten. While the primary effort has been concentrated on these two quasars, measurements were also made on 3C345, NRAO 512, and other sources.

Observations of Water-Vapor Sources with the "Westack" Interferometer

A.H. Barrett, B.F. Burke, K.Y. Lo - Massachusetts Institute of Tech.

J.M. Moran - Smithsonian Astrophysical Observatory

Radiometric observations with the "Westack" system, consisting of the 120-ft

Haystack and the 60-ft Westford antennas, began in 1972. These antennas form an interferometer with a baseline of 1.2 km in a direction 21°E of N.

The Westack system was described to some degree in the preceding Semi-annual, particularly its application at X-band. A more complete description of how the system operates, and of the changes for 22-25 GHz operation is found in E.1. below.

The objective of the present observing program is measurement of absolute positions of the water-vapor sources and monitoring of relative positions of the emission points that constitute these sources. By tracking the fringe phase, the Westack interferometer can achieve resolutions comparable with those obtainable from VLBI fringe-rate tracking. At this writing fringes have been detected in signals from W3, Orion A, W49, W51, W74(S), M17, ON2, RXBoo, VYCMa, and U Her.

D. Geodetic VLBI Program

When VLBI was a new concept, a group working at Haystack and MIT set out to demonstrate its feasibility for high-precision geodesy. In January 1969, a two-site experiment was conducted partly with borrowed equipment, between Haystack and Green Bank, in which the wide-band frequency switching technique was successfully applied and all baseline components were determined to within a few meters[1]. A second experiment in October 1969 utilizing Haystack, Green Bank and Owens Valley was even more successful, despite difficulties with two of the three hydrogen maser frequency standards used.

In mid-1970 NEROC received an Air Force contract providing Advanced Research Projects Agency support for a study of the problem of demonstrating to still higher precision the VLBI technique as a means of making precise geodetic measurements of relative location. This contract was extended in early 1971 to cover implementation of such a demonstration, using Haystack as one of the terminals together with several other antennas in various VLBI configurations.

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1. Precision Geodesy via Radio Interferometry: First Results
   Hinteregger, H.F., I.I. Shapiro, D.S. Robertson, C. Knight, R. Ergas
   MIT Dept. of Earth and Planetary Sciences.
   A.R. Whitney - MIT Dept. of Electrical Engineering
   A.E.E. Rogers - Haystack Observatory, NEROC
   J.M. Moran - Smithsonian Astrophysical Observatory
   T.A. Clark - NASA Goddard Space Flight Center
   B.F. Burke, MIT Research Laboratory of Electronics
   Submitted to Science

Configurations planned included:

North American Triangle

1) Haystack
2) 85-ft antenna of NOAA at Gilmore Creek, Alaska[1]
3) 210-ft "Mars" antenna at Goldstone (California) (with Owens Valley as an alternate).

European Triangle

1) Haystack
2) 85-ft antenna of Chalmers Institute, Onsala (Sweden)
3) 100-m antenna at Bonn (Germany)

Equipment for the experiments has been designed, constructed and tested in the North American Triangle. Plans are in progress for tests involving a European triangle. Haystack and Onsala will participate, but choice of the third site is not firm at present, due to some question concerning use of the Bonn telescope.

1. Project Equipment

Project equipment consists of X-band low-noise receivers, IF to video converters, phase calibrator, programmers for frequency switching, and data recorders. In most cases, four units of each item have been constructed in order to equip Haystack Observatory and three remote sites. However, a cryogenically cooled parametric amplifier is used at Haystack, a maser amplifier is used at the Goldstone Mars Site, while the other remote sites have room temperature paramps.

The system is designed to perform VLBI observations with a delay measurement error of under 1 nanosecond when signal-to-noise ratio is adequate.

Figure 4 shows the system block diagram for one site. All local oscillator signals are derived from the 5 MHz output of the frequency standard. A "phase calibrator" provides a signal derived in a separate chain to test the phase stability in a closed loop fashion. All units are entirely solid state

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1. The contribution of W.K. Klemperer, of National Oceanic and Atmospheric Agency, in the activation of the Alaska VLBI site, and his participation in our more recent experiments, is gratefully acknowledged here.

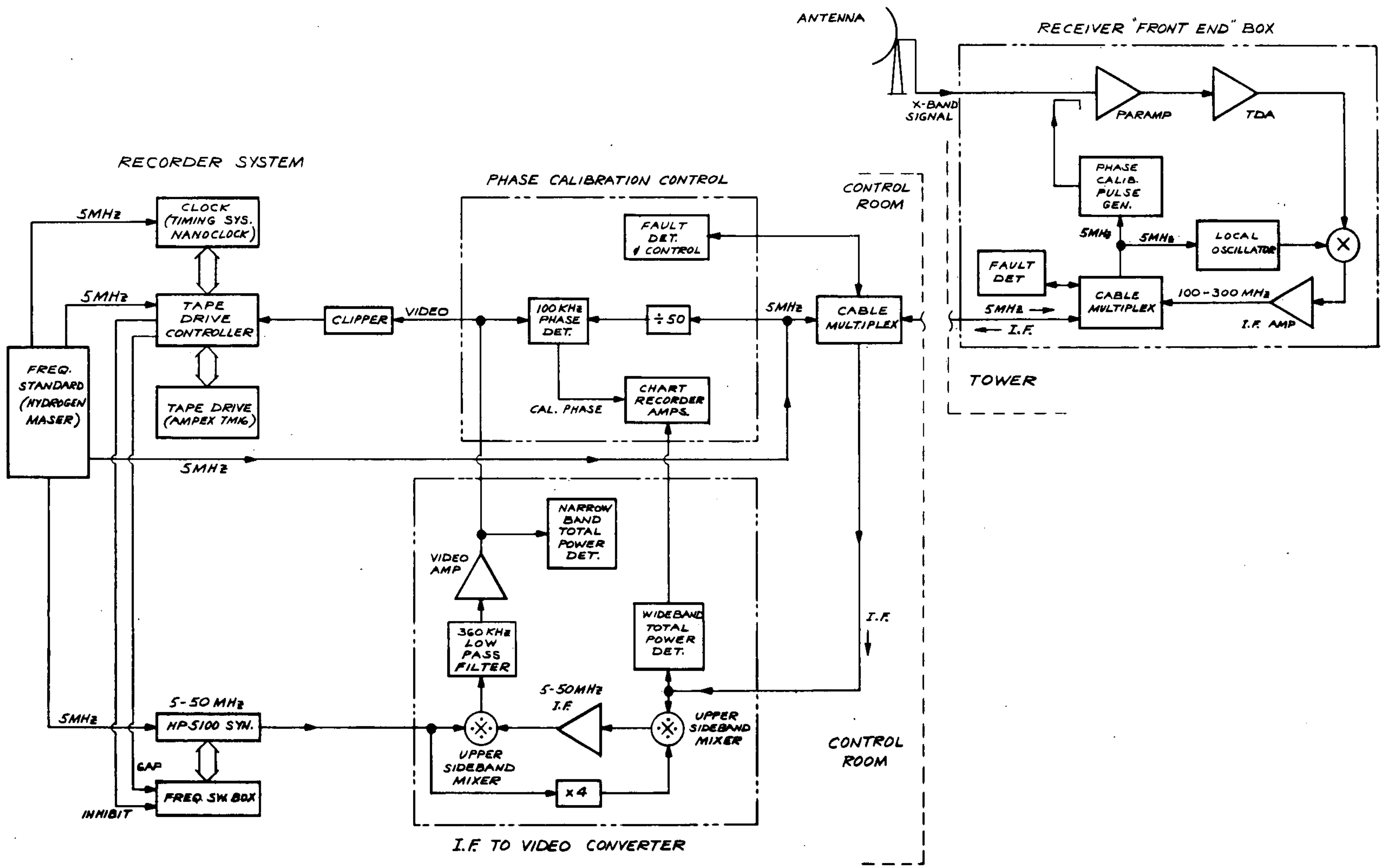

FIG. 4 GEODETIC VLBI SYSTEM FOR ONE SITE

circuitry (including the paramp pump - which is a Gunn effect diode oscillator) and have internal power supplies which operate on 120 volts A.C. System interconnection cables are kept to a minimum to allow simple installation at remote sites.

The remote site room-temperature paramp receivers have the following characteristics:

Tunable Frequency	7.5 - 8.5 GHz
3 db Bandwidth	80 MHz
Noise Temperature	180°K
IF Range	100 - 400 MHz
Overall Gain	Approximately 85 db
L.O. Lock Frequencies	7.3 - 8.3 GHz in 200 MHz Steps
Power Requirement	105 - 132 Volt 47 - 63 Hz Less than 500 watts.

The Haystack receiver has the same characteristics except that it has a cryogenically cooled paramp built by Comtech Laboratories, Smithtown, New York. This amplifier has the following characteristics relevant to VLBI.

Tuning Range		7.6 - 8.4 GHz
3 db Bandwidth		150 MHz
System Temperature		
In Haystack Radiometer Box	-	69°K at 45° elevation
In Radar Box	-	77°K at 45° elevation

The receiver at Goldstone is the JPL maser, which is tuned in a broadband fashion so that the system temperature remains within 22 - 30°K over a 50 MHz range, even though the gain varies by 15 db over this bandwidth. Gain variation is unimportant owing to the one bit recording system - provided the variation is within the dynamic range of the clipper, which is in excess of 40 db.

Also completed at Haystack and used this period were three of the Mk I digital tape recording systems which permit simultaneous recording of VLBI data at remote locations. Completion of the Mk I Processor and associated CDC-3300 software now permits simultaneous processing of three data tapes - requiring about 5 minutes per triplet, the fastest VLBI data recovery capability available at present! Final data output consists of measured delay, delay-rate, fringe phase and fringe amplitude for each run.

The first of several improved-design VLBI frequency switching units has also been completed at Haystack and checked out. Next period, all frequency-switching units will be replaced with the new design.

2. Test Experiments

Test experiments have been performed using Haystack, Goldstone, and Alaska. From measurements of total power the following efficiencies and system temperatures were determined:

SITE	T_{sys}, °K (45° el.)	Eff., %	Sens., °K/F.U.
Haystack P/R Box	77	40	0.15
Haystack R Box	69	45	0.15
Goldstone	30	50	0.6
Alaska	300	20	0.04

The expected correlations for the three baselines and those measured for 3C273 are:

BASELINE	EXPECTED CORRELATION	MEASURED
Haystack-Goldstone	1.0% $(F.U.)^{-1}$	3.5%
Haystack-Alaska	0.05% $(F.U.)^{-1}$	0.3%
Goldstone-Alaska	0.15% $(F.U.)^{-1}$	2.1%

Even after correction for the source contribution to the system temperature it was clear that the unresolved source flux is much larger on the Goldstone-Alaska baseline than on the other two baselines. Because of the source structure, it is difficult to verify the site sensitivities from the interferometric correlations.

Figure 5 shows the fringe phase measured on 3C273 for all three baselines. The observations were made on 9 May 1972 with maser frequency standards at each site.

The frequency switching sequence chosen for the North American triangle determinations is as follows:

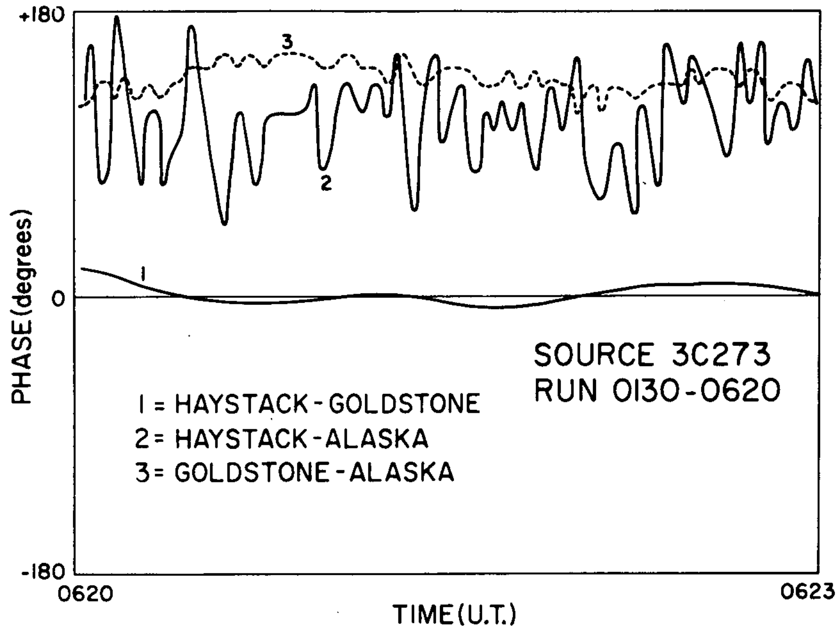

Figure 5. Fringe Phase Vs. Time for Three Baselines of North American Triangle

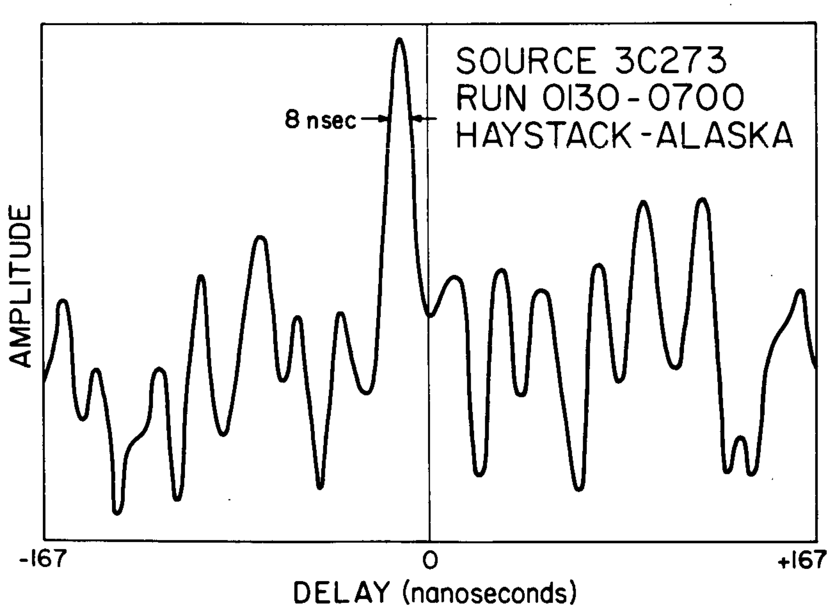

Figure 6. Sample Delay Resolution Obtained on Haystack-Alaska Baseline

FREQUENCY #	RF FREQUENCY
1	7849.9
2	7828.9
3	7852.9
4	7867.9
5	7897.9
6	7861.9

The fifth frequency is outside the Goldstone bandwidth, so that a five-frequency sequence with 39 MHz bandwidth is used on the Goldstone-Haystack and Goldstone-Alaska baselines, while the complete set of six frequencies is used on the Haystack-Alaska baseline. Thus, the Haystack-Alaska baseline has a larger bandwidth to compensate in part for the weaker signal on this baseline. Figure 6 shows a sample delay function observed on the Haystack-Alaska baseline.

3. Observations for Baseline Determination

A number of observing sessions, as summarized in Table III, have been undertaken during the past few months to determine the baselines of the North American Triangle.

Processing of the data is underway at Haystack using the above-mentioned Mk I Processor. Least square determinations of baselines, source positions, etc., are being performed at MIT on an IBM system 360 computer, but initial results were not ready in time for this report.

A.E.E. Rogers
J.I. Levine
S. Lippincott

E. Radiometric Instrumentation

1. 22-25 GHz Haystack-Westford Interferometer ("Westack")

During this period, development of the above-mentioned (Sect. C) Haystack-Westford interferometer reached a stage permitting observations of a number of water vapor sources, though room remains for improvement and simplification. It is fortunate indeed that the 60-ft inflated-radome-enclosed Westford antenna, though designed for X-band, has a quite useful capability in the frequency region of interest here.

At the 22 GHz water vapor frequency, the fringe spacing of this configuration is 2.2 seconds of arc. Both antennas are equipped with Aerojet mixers,

TABLE III

SUMMARY OF VLBI OBSERVATIONS - (NORTH AMERICAN TRIANGLE)

DATE	DAY #	OBSERVING[1] STATIONS	FREQ.[2] STANDARDS	# OF RUNS	COMMENTS
26 Feb. 72	57	H-0-A	M-0-R	7-0-7	Test only
29 Feb. 72	60	H-0-A	M-0-R	4-0-4	Test only
18 Mar. 72	78	H-G-A	M-M-R	0-6-6	Test only
21 Mar. 72	81	H-0-A	M-0-R	12-0-13	Tst. Expt. (Results Reported 11 Apr. 72)*
14 Apr. 72	105	H-G-0	M-M-0	13-13-0	
15 Apr. 72	106	H-G-0	M-M-0	231-231-0	
30 Apr. 72	121	H-G-A	M-M-R	8-2-8	
1 May 72	122	H-G-A	M-M-R	116-116-64	
9 May 72	130	H-G-A	M-M-M	129-129-46	Poor weather at H
10 May 72	131	H-G-A	M-M-M	52-52-10	
29 May 72	150	H-G-A	M-M-M	30-30-12	
30 May 72	151	H-G-A	M-M-M	151-151-79	
3 June 72	155	H-0-A	M-0-M	39-0-39	
4 June 72	156	H-0-A	M-0-M	6-0-6	
6 June 72	158	H-G-A	M-M-M	75-75-43	Obs. time scheduled by Jauncey et al.
7 June 72	159	H-G-A	M-M-M	36-36-14	
27 June 72	179	H-G-0	M-M-0	107-107-0	
28 June 72	180	H-G-0	M-M-0	94-94-0	

NOTES: 1. H = Haystack, G = Goldstone, A = Alaska
0 = Not observing, 1 = Observing but non operationsl (i.e., equipment problem or setup error)

2. M = Maser, R = Rubidium, 0 = Not applicable

* At a Project meeting at AFCRL

giving a system temperature (double sideband) of roughly 1000°K. Both local oscillators are synchronized to the hydrogen maser standard at Haystack, and the reference frequencies are sent to Westford at 120 MHz over a phase-stabilized cable. The received signals at Westford are returned to Haystack at an IF frequency of 30 MHz with a bandwidth of 10 MHz.

Both Haystack and Westford IF signals are converted essentially to video, though the local oscillator signal used to convert the Westford signal is offset by a controlled amount in order to remove most of the fringe rate. The two video signals are cross-correlated in the same one-bit correlator used in spectral line work. Either signal may be delayed up to 50 correlator clock periods before cross-correlation.

Correlator averages for every 100 msec., along with time and pointing data, are recorded on tape by the U490 pointing computer. Resulting tapes are subsequently processed on the CDC 3300 computer for fringe phase, fringe rate, etc.

J.C. Carter
K.Y. Lo, MIT

2. K-Band Maser Development

A 22-24 GHz helium-cooled maser amplifier is being developed at Haystack with the collaboration of S. Yngvesson of University of Massachusetts. U. Mass., Harvard and MIT are each providing support for this development.

Overall progress has been slower than anticipated principally because the project engineer transferred to another MIT department and the responsible project technician was absent due to protracted illness.

A suitable piece of ruby was obtained. It has been polished to required tolerances and a chrome-gold slow-wave comb structure has been sputtered on to one surface at MIT Lincoln Laboratory.

Metallized chrome-gold Al_2O_3 substrates for the microstrip transmission lines were diamond ground to dimensions. Photo-etching of the conducting strips is in progress in a vendor's shop.

A final design of room temperature flange and header assembly has been fabricated. Parts for the monitoring and control panel and circuitry are being obtained. Meanwhile, the existing controls for the present X-band maser will be adapted for testing the new K-band unit. We presently estimate that bench r.f. testing at U. Mass. under Yngvesson's direction should be completed in October.

J.M. Sobolewski
L.P. Rainville
(now at Lincoln Laboratory)

3. Software

Among the computer programs prepared in support of radio astronomy activities were the following:

- A VLBI correlation program for the CDC-3300, designed to operate with the new Mk I Processor mentioned in D. The combination has greatly accelerated the processing of Mk. I VLBI data tapes.

- A program to search the Smithsonian Star Catalog tapes for stars of given characteristics and to assemble the output in a suitable format for display.

- Pointing system mods to permit manual entry of offsets up to $\pm$ 10 degrees via a push-button device.

- Miscellaneous other programs and program mods were undertaken in support of particular radio astronomy projects.

R. A. Brockelman

III. RADAR PROGRAMS

A. Moon

In accord with Contract NAS 9-7830 with NASA Manned Spacecraft Center, Houston, this section reports progress in our program for measurements of lunar topography by interferometric radar techniques. In this method, radar range, differential Doppler shift, and interferometer phase provide three dimensions permitting topographic determinations. Haystack and the nearby 60-foot Westford antenna are used in this work.

1. Observations

The routine data gathering phase of this program is well along. Only about 60 hours of observations were taken, emphasizing mare floors and rims of particular interest, including a small area of Mare Orientale. A series of overlapping measurements were taken on each, with the intent of reducing large inconsistencies that result from imperfect ephemerides when measurements are widely separated in time.

At present, all measurements made before 1 April 1972 have been reduced to maps on appropriate cartographic projections, using uncorrected ephemeris parameters. Reduction of the remaining maps will require about 700 hours of computer time and will take six to eight months at the level of effort now possible.

2. Processing Improvements

A computer program was written to remove parallax distortions from the selenographic positions of elevated features on the topography maps. This well-known effect results when areas of a planetary surface are observed by projection or photography along a direction other than the local planetary vertical.

When a number of such observations are available at a variety of directions, the elevation of each identifiable feature can be calculated from them[1]. In the present case, however, surface elevations are already available directly from the interferometer measurements, making it possible to adjust the maps into a pseudo-vertical projection.

The correction program appears to remove most, though not all, of the obvious distortions in the maps.

Figure 7 is a map of the Alphonsus region that has appeared in a previous QPR. The most evident distortions are in the southwestern walls of both the craters Alphonsus (at 2.0°W, 19.0°S) and Alpetragius (at 4.2°W, 16.0°S). During this observation the lunar subradar point was located at (3.1°E, 1.7°S), and the Doppler axis was parallel to the linear artifacts that appear in the contour lines at the top right corner of the map. Note that the slopes that face in the direction of these artifacts and toward the subradar point seem steeper than identical slopes facing oppositely.

This distortion occurs because elevated points of the surface will appear in the map to be displaced a distance proportional to their height toward the subradar point. In range-doppler coordinates, the location of a point on the mean spherical surface is

$$\vec{R}_o = \hat{i}x + \hat{j}y + \hat{k}z$$

If the point is radially displaced above the surface by a height h, then the new location is

$$\vec{R}_o\left(1 + \frac{h}{|R_o|}\right) = \hat{i}\,(x + \Delta x) + \hat{j}\,(y + \Delta y) + \hat{k}\,(z + \Delta z)$$

In the delay-doppler map, the displacements are then

$$\Delta x = \frac{x}{|R_o|}\,h$$

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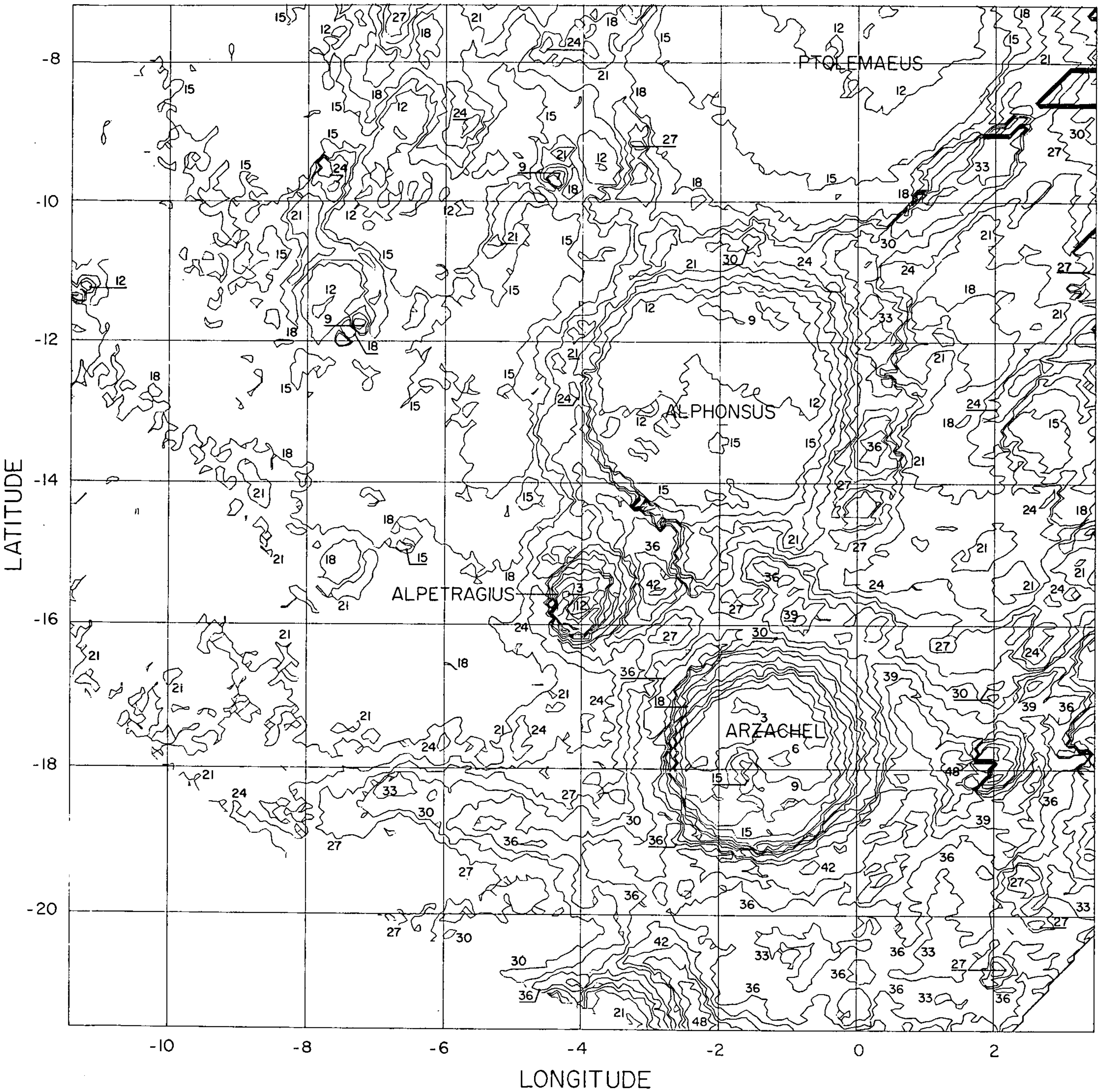
1. See corresponding reference at end of Section.



CONTOURS IN HUNDREDS OF METERS, 300 METER INTERVALS

FIGURE 7. UNCORRECTED RADAR TOPOGRAPHY FOR THE ALPHONSUS REGION, SHOWING APPARENTLY ASYMMETRICAL SLOPES ON THE WALLS OF DEEP CRATERS.

in the frequency direction, and

$$\Delta z = \frac{z}{|R_o|} \quad h$$

in the time-delay direction. This amounts to a displacement in the plane containing the doppler axis and the given surface feature, and in the direction of the subradar point as described above.

Figure 8 is a reprocessed map of the same region. Note that the asymmetrical slopes are no longer in evidence. There appears, however, to be a small over-correction of the original problem. Its cause is as yet unclear, but it may depend on the long-known problem of ephemeris discrepancies. This latter problem, in turn, may now be on the way to solution, as described below.

3. The Ephemeris Problem.

Ephemeris-dependent parameters that are used in the reduction of the topography observations have heretofore been obtained partly from the MIT Lincoln Laboratory Planetary Ephemeris Program (PEP) and partly from a separate computation of lunar librations, based on the American Ephemeris and Nautical Almanac and its Explanatory Supplement. Since the PEP program is intended for single observation points rather than areal maps, it has provided, until now,only our lunar center-of-mass predictions.

We now have almost completed a 6-month effort to obtain libration-based parameters entirely from PEP, in a form useable for mapping. The first results appear to show a discrepancy between PEP and the local computation that is easily large enough to have caused most of our past difficulties with mismatch and slope during the assembly of large-area maps from individual observations. When tests of the PEP parameters are completed, we intend to use the new parameters to modify the orientation and phase of the finished maps without major amounts of re-processing. It is hoped that this will bring closer a global fit from the radar data.

4. Analysis and Publications

Alphonsus Region

A paper[2] has been accepted for publication in Science in October containing the work on the topography of this region.

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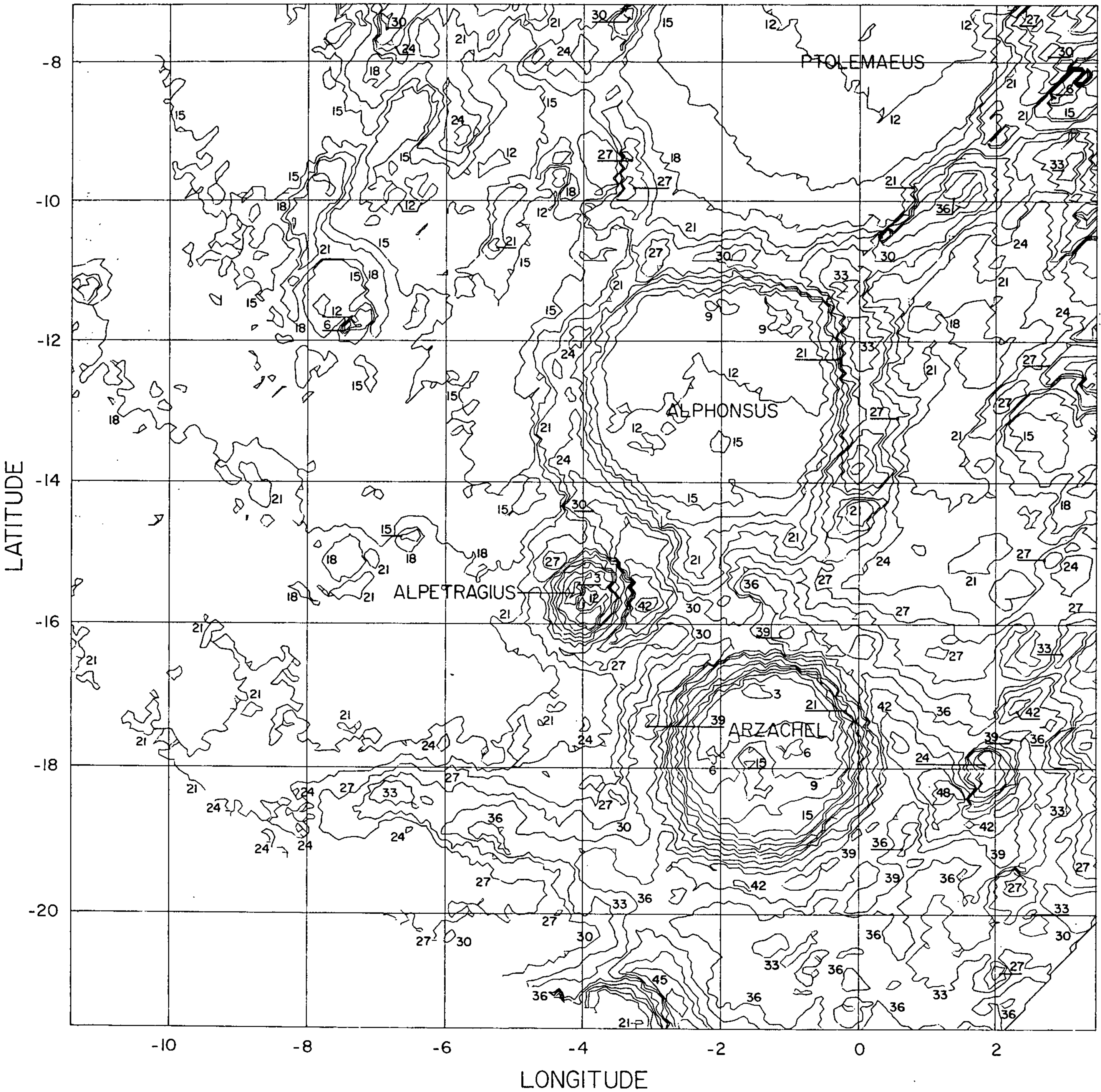
2. See corresponding reference at end of Section.



CONTOURS IN HUNDREDS OF METERS, 300 METER INTERVALS

FIGURE 8. RADAR TOPOGRAPHY FOR THE SAME AREA AS FIGURE 7, CORRECTED FOR ELEVATION PARALLAX.

Descartes Region

Two papers[3,4] have been submitted for publication in the Apollo 16 90-day preliminary science report, discussing and interpreting the radar backscatter characteristics of this region. We intend to expand at least one of them for publication in an appropriate journal, including such topography data as may seem appropriate.

Radar Interferometry Techniques

One paper on methodology[1] has been accepted for publication in the same issue of Science as the Alphonsus work[2]. It discusses in general terms the problem of remote measuring of lunar and planetary topography by various means, including radar interferometry. Another paper describing in some detail the present Haystack-Westford radar interferometer system (which we call "Hayford" as opposed to "Westack" for the radiometric configuration) has already appeared[5].

S.H. Zisk

References

1. Lunar Topography: Global Determination by New Radar Methods
   I.I. Shapiro, S.H. Zisk, A.E.E. Rogers, M.A. Slade and T.W. Thompson
   Science (In Press, October 72)

2. Lunar Topography: First Radar-Interferometer Measurements of the Alphonsus-Ptolemaeus-Arzachel Region
   S.H. Zisk
   Science (In Press, October 72)

3. Apollo 16 Landing Site: Summary of Earth-Based Remote Sensing Data
   S.H. Zisk, Harold Masursky, D.J. Milton, G.G. Schaber R.W. Shorthill, T.W. Thompson
   Apollo 16 90-day Preliminary Science Report, NASA Manned Spacecraft Center, Houston, Texas (Submitted July 1972)

4. Calibration of Radar Data from Apollo 16 Results
   S.H. Zisk, H.J. Moore
   Apollo 16 90-day Preliminary Science Report, NASA Manned Apacecraft Center, Houston, Texas (Submitted July 1972)

5. A New, Earth-Based Radar Technique for the Measurement of Lunar Topography
   S. H. Zisk
   The Moon (Submitted March 1972)

B. Mars

During the first 6 months of 1972, Mars was at distances in excess of 1 a.u. and did not allow ranging observations of useful precision, with the exception of 10 and 11 February when a region of exceptionally high reflectivity was known (from earlier observations in 1971) to lie in the subradar region of Mars. On these dates observations were obtained with 2- to 4-microsecond accuracy at a distance of 1.55 a.u.

All data taken in 1971 and 1972 have been reduced to yield improvements to the Martian orbit, a mean equatorial planetary radius (about 3394 km), a profile of surface heights at a variety of latitudes (see Haystack Semiannual Report dated 15 January 1972), and r.m.s. slopes and dielectric constants over many areas of the planet. The latter have been derived through the process of fitting templates derived from an analytic expression for a scattering law (see below) to the data and noting the one yielding the least sum of squared residuals. The transmitter and receiver characteristics are accounted for in generating the template.

The form of the scattering law used is:

$$\sigma_o(\theta) = \frac{\rho_o C}{2} (\cos^4\theta + C\sin^2\theta)^{-\frac{3}{2}}$$

where $\sigma_o(\theta)$ is the specific radar cross section (i.e. per unit surface area), ρ_o is the surface Fresnel reflection coefficient at normal incidence, C is a constant related to r.m.s. surface slopes for quasi-specular scattering, and θ is the angle of incidence with respect to the local vertical. In the fitting process, C is recovered from the echo behavior in the "tail" region, i.e., at delays greater than the initial return, while the strength of the initial return (i.e., at $\theta = 0$) gives the product $\rho_o C$. The dielectric constant, in turn, is derived from the reflectivity as:

$$\varepsilon = \left[\frac{1 + \rho_o^{\frac{1}{2}}}{1 - \rho_o^{\frac{1}{2}}}\right]^2$$

while the r.m.s. slope (in radians) is equal to $C^{-\frac{1}{2}}$. A plot of the results obtained for a range of longitudes between 50° and 120°W, and at a latitude of 14.2°S, is shown in Figure 9. Of particular interest is the behavior of the dielectric constant over this relatively smooth region, where it can be seen to increase steadily from about 1.8 to about 5.0. Surface heights over this interval are also rising steadily (see Figure III-1a of Haystack Semiannual Report dated 15 January 1972) and it is interesting to speculate that the extremely low values of dielectric constant which occur in the lower portions of the surface are associated with dust layers up to a meter or more in depth.

G.H. Pettengill

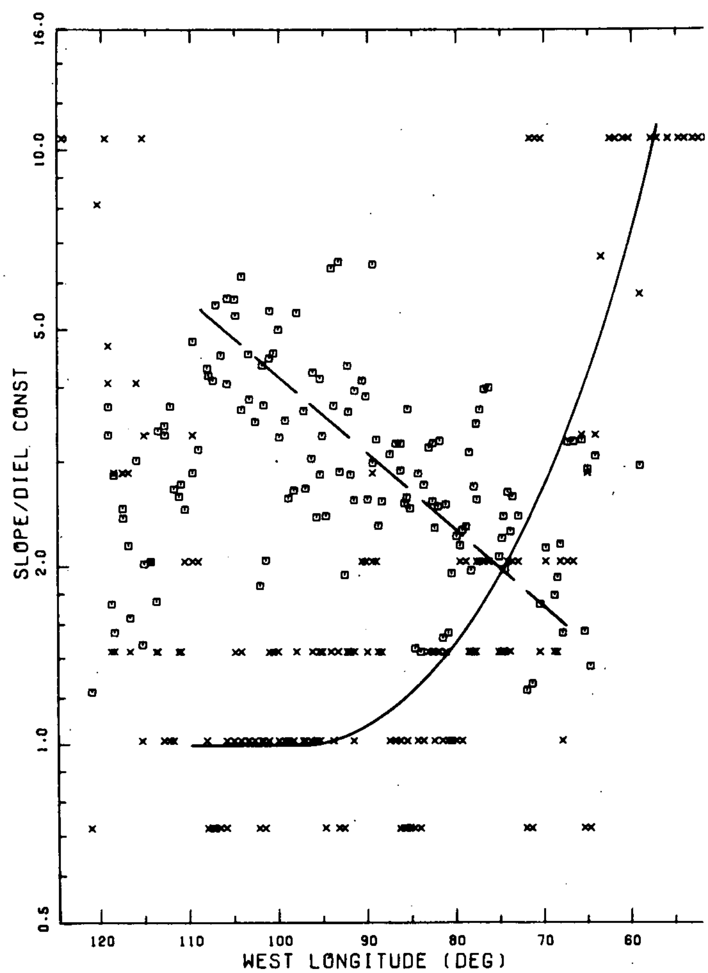


Figure 9

Dielectric constant (open squares) and r.m.s. surface slopes (crosses, in degrees) as a function of west Martian longitude for a latitude of 14.2°S. Data were obtained from 3.8-cm radar observations in August 1971.

C. Mercury

An intensive series of topographic observations of Mercury were accomplished near the inferior conjunction of 31 March 1972. This was a cooperative venture with the Arecibo Observatory; daily radar coverage was obtained by each observatory operating 4 days a week from 19 March to 14 April. Sufficient simultaneous observations were made to aid in uncovering the reasons for an apparent discrepancy of 8 microseconds in delay between Arecibo's and Haystack's observations of Mercury. The Haystack topography data are currently being analyzed but a preliminary look indicates that a height accuracy of better than 1 km at a longitude resolution of a degree was obtained for much of the data.

D. Venus

Venus was the object of several different investigations centered about its inferior conjunction of 17 June 1972. Range delay data have been acquired throughout this reporting period while the radar system was on-line. Most of these observations were performed with a 24-microsecond pulse width, but a new mode of operations was initiated on 15 June that used a 4-microsecond pulse width and 2-microsecond range delay sampling. This is the finest resolution in range delay achieved at Haystack for planetary radar operations. With further refinement in data analysis, submicrosecond delay accuracy should be achieved with these data. The longer 24-microsecond pulse ranging observations are also used for topography determination. Resolution in frequency allows a topographic height profile to be generated along the equatorial region (Ingalls, and Rainville, 1970).[1]

Analysis of Venus radar echo-delay and total cross section data has yielded a tentative result (Figure 10) for the equatorial gravity equipotential. Unfortunately, the uncertainties in this curve, both in the scale and in the variations, are largely due to lack of calibration data for the cross sections and of accurate values for the relevant atmospheric parameters. Both sources of uncertainty should be removable in the future. A detailed discussion of the analysis has been submitted to Science.[2]

Observations of Venus were also made in an attempt to detect reflections from cloud layers or to set an upper limit on their reflectivity. Preliminary

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1. "Radar Measurements of Venus Topography...", Ingalls, R.P. and Rainville, L.P., NEREM-70, Record 12, 1970.

2. "Venus: Radar Determination of Gravity Potential", Shapiro, I.I., Pettengill, G.H., Sherman, G.N., Rogers, A.E.E., and Ingalls, R.P., Submitted to Science.

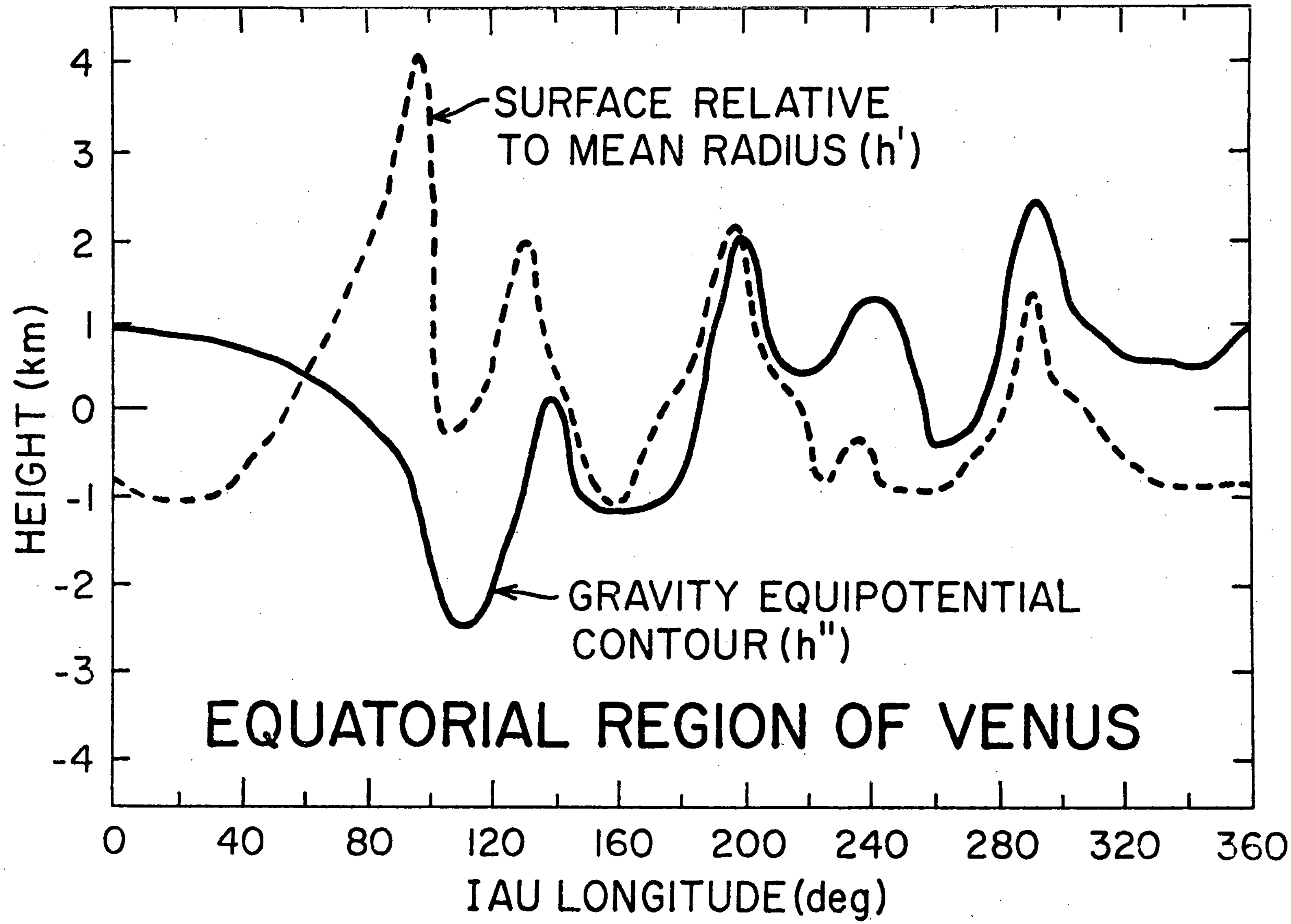

Figure 10. Comparison of the surface heights on Venus with a gravity equipotential contour. The surface heights are based on round-trip radar echo delays from published and recent, unpublished data. The gravity potential contour is derived from radar cross section data obtained at the Haystack Observatory; the uncertainties in both the scale and variations of this curve are large (see text). Latitude variations have been suppressed with both curves referring to averages along a narrow ($\pm$ 10°) longitudinal band centered on the equator of Venus.

analysis of these data indicates no evidence of such reflections, and seems to set an upper bound of about 10^{-3} times the cross section of the surface.

Unambiguous reflection mapping observations were made on 6 days in June using the Haystack-Westford radar interferometer. Both 500- and 250-microsecond pulse width observations were made to optimize coverage and resolution respectively. The mapping data are still being processed, but preliminary results compare favorably with earlier data (Rogers & Ingalls, 1969)[3].

CW spectra of both polarized and depolarized Venus echoes were obtained in a program to determine the rotation vector of the planet. These spectra will be compared with measurements made in 1964 at Goldstone when Venus went through an inferior conjunction with almost identical viewing aspects from earth. The identification and location in frequency of corresponding reflection features seen in both 1964 and 1972 conjunctions will result in the determination of more precise rotation parameters for the planet.

R.P. Ingalls, I.I. Shapiro

E. Satellite Observations

Late in 1971 several exploratory radar observations were made with the Haystack Planetary Radar on Lincoln Laboratory Experimental (Communications) Satellite LES-6 to demonstrate the feasibility of observing, accurately locating and obtaining reflection "signatures" from satellites at synchronous altitudes (approximately 40,000 km) and beyond. Aside from the 210-ft Goldstone system, which is heavily committed to space missions, Haystack represents the only major instrument capable of such measurements.

The success of these tests led to a request from MIT Lincoln Laboratory for about 100 hours of such measurements on different satellites of interest during the first half of 1972. An appropriate incremental cost arrangement was worked out to support the required radar operations and minor equipment modifications. It was also mutually agreed that satellite observations would be scheduled well in advance, in accord with procedures established for other experiments.

Operations during this period were aimed largely at becoming more proficient at finding and gathering useful backscatter data, primarily on four satellites of interest. Dual-polarization coverage was obtained beginning about the middle of the period, and operations were scheduled so as to obtain sets of data for the maximum possible range of aspect angles.

A highlight of the period was participation in a cooperative experiment in which the narrow-beam communications antennas on one of the satellites were

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3. Rogers, A.E.E. & R.P. Ingalls, "Venus: Mapping the Surface Reflectivity by Radar Interferometry", Science 165, 22 August 1969.

moved in a systematic fashion while the radar signature was being recorded. The effect of the movement was immediately obvious, and the data are being processed to define the contribution of such antennas to the observed signature.

Toward the end of the period, negotiations were nearly completed with Lincoln Laboratory for an extension of the program through the next semi-annual period. Certain system modifications to improve operating convenience and the resolution of the measurements are included in this proposed program extension, under which, of course, the required funding will be provided.

R.P. Ingalls, S.H. Zisk

F. Radar Instrumentation

1. Hardware

The radar transmitter used VA-949BM klystrons S/N 22 and S/N 25 for this period. The arcing problem with S/N 25 has diminished but the tube still is predisposed to arcing if pulse radar operations are mixed with cw. The transmitter has been operated with a conservative 250 to 300 kw in the cw mode. Two new klystrons, S/N 24 and S/N 26, have been received from Varian but have not been placed in service.

The major modification to the radar system has been the incorporation of the Comtech paramp which was procured under the Geodetic VLBI program, but which has broad applicability at X-band frequencies. Waveguide modifications are complete, but a major revision and upgrading of waveguide switch control functions was delayed until September. Currently the existing control panel is used with those modifications required to connect to the paramp and VLBI receivers. The use of the Comtech paramp for radar operations eliminates the maser helium fill and hold time limitations. For radar work, the system temperature in the PR box with the paramp is typically 65° - 70°K as opposed to approximately 45°K with the X-band maser. Radar operations will use the paramp for all except the most sensitive applications. A more general discussion of the Comtech paramp performance is included under radiometric instrumentation.

A Radar Data Processing unit has been built and added to the Haystack Real Time Decoder. This system enables ranging down to 2 μsec sampling while reducing the computer I/O load by at least a factor of 17. The new unit was used successfully at the June inferior conjunction of Venus. All of the pseudo-random code demodulation now is performed outside the CDC-3300, including the coherent summation of code intervals. This allows the use of a truly real-time computer program to perform spectral analysis and thus eliminates the two-phase operation formally required. The code length of 255 elements is fixed, but there is flexibility in setting both pulse width and the number of codes summed. This allows the delay resolution and frequency coverage to be independently specified, within limits.

R.P. Ingalls
J.I. Levine
M.H. Leavy

2. Software

A CDC-3300 program - Short Pulse Planetary Ranging - was written for use with the new Radar Data Processing unit and Real Time Decoder, as mentioned above. A real time presentation of the received signal on a CRO display is a new feature available with this program, in addition to the real-time generation of a complete range-doppler map.

A new real-time computer program was prepared for the Haystack-Westford (HAYFORD) radar interferometer mapping study of Venus at inferior conjunction. This program provides for baud lengths of 250 or 500 microseconds. In this system, the software decodes the received signal in real time, records the decoded complex samples on magnetic tape and performs an incoherent integration of the range-delay profile for display at the end of a receive period. Fourier analysis and mapping are performed later by "off-line" programs.

A lunar parallax program was written to correct for the parallax offset of an elevated point on the moon. The program inputs the radar data (range-doppler) in complex form; converts it into magnitude and phase data; performs corrections to reduce each point on the moon's surface to its radially projected position on a sphere, and records the corrected data on tape for subsequent coordinate transformation and mapping (see III.A).

A special "bootstrap" tape has been prepared for the U490 Pointing Computer which features automatic selection of the satellite program and eliminates several initialization procedures required by the normal master bootstrap procedure.

A real time program based on the planetary CW spectrum program has been prepared for the synchronous satellite observations described earlier. It records on tape the time delay complex samples from the radar receiver, and also performs a Fourier analysis, the spectrum from which is displayed at the end of a run. The recorded tapes are finally processed by Lincoln Laboratory.

Work is progressing on a search mode addition to the above program which will provide a real time display of the spectrum, plus "hit" detection and "tagging" (with azimuth and elevation) so that the target can be easily relocated after a first detection during search.

R.A. Brockelman
G.W. Armistead
J.R. Burdette

APPENDIX

Publications for January - June 72

Low-Energy X-Rays Ruled Out as Interstellar Ionizing Mechanism
Toward K3-50
E.J. Chaisson, L.E. Goad
Astrophys. J. 171, No. 2, L61-L65, 15 January 1972

(R) Venus: Topography Revealed by Radar Data
D.B. Campbell, R.B. Dyce, R.P. Ingalls,
G.H. Pettengill, I.I. Shapiro
Science 175, No. 4021, 4 February 1972

(R) The Topography of a Swath Around the Equator of the Planet Venus
From the Wavelength Dependence of the Radar Cross Section
A.E.E. Rogers, R.P. Ingalls, L.P. Rainville
Astronomical Jrnl., February 1972

(R) Radar Measurements of Mercury: Topography and Scattering
Characteristics at 3.8 cm.
R.P. Ingalls, L.P. Rainville
Astronomical Jrnl., Vol 77, #2, March 1972

(R) Lunar Topography: First Radar-Interferometer Measurements of the
Alphonsus-Ptolemaeus-Arzachel Region
S.H. Zisk
Science (Accepted for publication)

(R) A New, Earth-Based Radar Technique for the Measurement of Lunar Topography
S.H. Zisk
The Moon, Vol. 4, No's. 3 & 4, June/July 1972

(R) Lunar Topography: Global Determination by New Radar Methods
I.I. Shapiro, S.H. Zisk, A.E.E. Rogers, M.A. Slade
and T.W. Thompson
Science (Accepted for publication)

Precision Geodesy via Radio Interferometry: First Results
H.F. Hinteregger, R. Ergas, C.A. Knight, D.S. Robertson,
I.I. Shapiro, A.R. Whitney, T.A. Clark
Science (Submitted)

Interferometric Observations of an Artificial Satellite
R.A. Preston, R. Ergas, H.F. Hinteregger, C.A. Knight,
D.S. Robertson, I.I. Shapiro, A.R. Whitney
Science (Submitted)

3C279: Evidence for a Non-Superrelativistic Model
W.A. Dent
Science 175 4026, 10 March 1972

(R) Radar Related Research

(R) Infrared and Radar Maps of the Lunar Equatorial Region
R.W. Shorthill, T.W. Thompson, S.H. Zisk
The Moon, Vol 4, No's. 3 & 4, June/July 1972

(R) Estimates of Block Frequency Distributions for North and South Ray
Craters, Descartes Area of the Moon
H.J. Moore and S.H. Zisk
Jrnl. Geophys. Res. (Submitted)

Observations of Recombination Lines at Ku-Band
G.D. Papadopoulos, K.Y. Lo, P. Rosencranz, E.J. Chaisson
Astrophys. Lett., Vol 10, March 1972

(R) Mercury's Perihelion Advance: Determination by Radar
I.I. Shapiro, G.H. Pettengill, M.E. Ash, R.P. Ingalls,
D.B. Campbell, R.B. Dyce
Phys. Rev. Letters, Vol 28, p. 1594, 12 June 1972

(R) Venus: Gravity Field Determination by Radar
I.I. Shapiro, G.H. Pettengill, A.E.E. Rogers, R.P. Ingalls
Science (Submitted)

A Flux Density Scale for Microwave Frequencies
W.A. Dent
Astrophys. Jrnl. (Submitted)

High Resolution Observations of the Chromosphere at MM and CM Wavelengths
M. Simon
Solar Physics (Submitted)

Some Characteristics of an Operational System for Measuring UT-1
Using Very Long Baseline Interferometry
J.M. Moran
Space Research, Vol. XIII, 1972

Evidence for Spatially Independent Outbursts in Compact Radio Sources
W.A. Dent
The Astrophysical Journal, 175-L55-L58, July 15 1972

Observations of Sources of Maser Radioemission with Angular Resolution
$0\overset{''}{.}002$
B.F. Burke, K.J. Johnston, V.A. Ejanov, B.J. Clark, L.R. Kolgan,
V.I. Kostenko, K.Y. Lo, L.I. Matveyenko, I.G. Moiseev, J.M. Moran
S.H. Knowles, D.C. Papa, G.D. Papadopoulos, A.E.E. Rogers, P.R. Schwartz.
Astronomical Journal (USSR) 49(3), 465-469, May 1972